The required mechanical precision can be estimated from the expression for axial compression, holding the cavity vertically—without symmetry—from one end alone

$$\boxed{\frac{\delta f}{f} = -\frac{\delta L}{L} = \frac{\rho L}{2Y}a}, \tag{2}$$

Compared with a horizontal orientation, this predicted sensitivity is larger by a serious factor, L/(σ*h), a factor of ~5x from dimensions and ~5x again from loss of the Poisson ratio. This scale is 28-fold larger (V vs H) for the cavity of FIG. **1**. However, using the symmetry idea, in the machining of the structure we can expect a precision of about 0.1 mm out of 100 mm cavity length. This is an asymmetry factor of $\epsilon=2/1000$ in our favor. So a nominally-fabricated vertical cavity **202** should be able to give a sensitivity ~20× reduced from that calculated for horizontal use. The shortening to 100 mm cavity length is prudent relative to its weight, and also reduces the sensitivity.

An experimental trial used an available ULE cavity **202** of 50 mm length and 12.5 mm diameter, having a finesse ~46×10^3 and a linewidth of 65 kHz. This length approximates the height of our first cavity of FIG. **1**, but we lose the favorable σ=0.17 factor in Eq. 1. Support at the vertical midplane **204** was approximated by mounting the cavity into a Zerodur disk **206**, drilled to accept the cavity's diameter, plus a ¼ mm gap to be filled with silicone RTV adhesive **208**. The length-wise centering was accurate to ~0.5 mm. The disk had been predrilled to its midplane from both faces to provide 2 sets of 3 holes **210** which could receive the 3 vertical mounting posts **212**.

For convenience, the mounting base was formed from aluminum, and comprised a footing **214**, and legs **216**, leading to pins **212**. In one embodiment, the pins are formed of a softer material such as Teflon.

With the lighter end of the cavity oriented up, one could add bits of In (indium) wire (not shown) on the top to increase the acceleration sensitivity of this less-sensitive half. In this way the coefficient could be trimmed from 18 to below 10 kHz/ms^{-2} (observed at 1064 nm), limited by cross-coupling and in-equivalence of the PZT shakers used in the tests under each of the 3 legs. For comparison, Eqs. 1 and 2 predict 9.8 kHz/ms^{-2} for horizontal and 232 kHz/ms^{-2} for unsymmetrical vertical mounting (at 1064 nm). So even our imperfect mounting symmetry bought us a factor ~23× reduction of the nominal vertical acceleration sensitivity. Compared to the horizontally-mounted case, by "going vertical" we lose the σ=0.17 factor, and have a longer scale dimension along the cavity axis. Still, by use of more precise fabrication symmetry, we can win a better sensitivity reduction factor at a particular length, plus we have the ability to trim to even better reduction. Also the smaller cavity and vertical geometry is better for the dual-layer thermal controls that may be needed: available ULE normally needs to be cooled to reach the temperature where its length is thermally-stable, and the Peltier coolers need a big surface for their heatsink. Additionally, the vertical geometry can be used with a spherical or doubled-cone overall cavity shape which can provide a calculated further acceleration sensitivity reduction of about 3× relative to that of the full cylindrical spacer.

Preferably, the cavity spacer **222** and the collar **206** are formed of a low thermal expansion material. Low thermal expansion materials generally have a thermal expansion coefficient (TEC) of at least less than $10^{-7}K^{-1}$, and very low thermal expansion materials have TEC of less than $10^{-7}K^{-1}$. This latter performance is difficult to achieve and generally requires the use of a glass ceramic such as Zerodur which is heat treated and annealed, and then ground into its shape (molding reduces the TEC too much). This careful fabrication can result in a material with TEC very near 0 at the temperature of operation.

FIG. **3** is a simplified side-section diagram illustrating a second preferred embodiment of the present invention, wherein the reference cavity **202** is vertically mounted from above. Many of the elements in this figure are the same as those of FIG. **3** and are numbered the same. Cavity **202** is still suspended vertically at its midplane **204**. Disk **306** is similar to disk **206** of FIG. **2**, except that bores **310** allow it to be suspended from wires **316** (rather that being supported by posts **212**) so the holes **310** need to have a smaller diameter above (just for clearance of the wired diameter) and a larger diameter below, where the attachment is effected with a thicker retaining element **312** clamped onto the wire (retaining element **312** could be simply a blob of epoxy at the end of wire **316**). Again collar **306** is supported at approximately its midplane.

Wires **316** are in turn suspended from support beam **314**. Leaf springs **318** may be used to absorb vibration, as in FIG. **3**. In this case, wires **316** pass through beam **314** via holes **315**.

FIG. **4** is a simplified side-section diagram illustrating a third preferred embodiment of the present invention, wherein cavity **402** is supported at its geometrical midplane **204** via holes **410** drilled into the cavity spacer **422** itself. Hence spacer **422** also forms the collar in this embodiment. Spacer **422** is much thicker than in the previous embodiments, extending out far enough to allow room for bores to accommodate supports **416**.

FIG. **5** is a simplified side-section diagram illustrating a fourth preferred embodiment of the present invention, wherein collar **506** is an integral unit with cavity spacer **522**. This embodiment is similar to that of FIG. **4** in that the cavity spacer is constructed to also form the collar for supporting the cavity. However, cavity **502** is shaped differently from cavity **402**, because its collar **506** is disposed around only a central portion of the cavity. This allows for the use of less LTE material and shorter bores **510**, but the shape is a bit more complex to fabricate. Note that the embodiments of FIGS. **4** and **5** could be adapted to suspended configurations if desired.

What is claimed is:

1. Apparatus for reducing the effects of vibration on a reference cavity having end mirrors and a spacer by mounting the cavity vertically and supporting the cavity at its geometrical horizontal midplane, the apparatus comprising:

a collar formed around the cavity spacer such that the geometrical horizontal midplane of the cavity is closely aligned with the geometrical horizontal midplane of the collar; and

means for supporting the collar such that the cavity is suspended from the collar;

wherein the cavity spacer is formed of a low thermal expansion material;

wherein the collar is formed of a low thermal expansion material; and

wherein the collar provides uniform symmetrical support to the cavity.

2. The apparatus of claim **1** wherein the collar is substantially vertically symmetrical except that features in the top half of the collar are rotated around the collar's axis from features on the bottom half of the collar.

3. The apparatus of claim **1** wherein the collar and the cavity spacer are an integrally formed element.